of the gradually varied conditions present in the district where coagulation is taking place.

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The Influence of Increased Barometric Pressure on Man.—II.

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In a previous communication, we gave reasons for thinking that decompression symptoms may be avoided by maintaining a steady rate of 20 minutes per atmosphere during this process.

The actual time selected was purely empirical, being based on the statistics of Caisson Works, Diving Operations, and Laboratory Experiments. It is clear that a more scientific foundation would be obtained if we could determine (1) the rate at which the tissue fluids are saturated with nitrogen; (2) the rapidity with which dissolved gas escapes during decompression. The most direct method would be to analyse samples of arterial blood under various pressure conditions; but this is not, unfortunately, practicable in the case of man. Another way is the examination of venous samples under similar circumstances. This plan can be followed, and we hope to communicate some results in another paper, but the technic is difficult and still in need of improvement. A third line of research is the indirect determination of the tissue gases, and this will be discussed in the present communication.

If a condition of diuresis be produced by drinking considerable amounts of water, the profuse secretion of urine which results will afford some measure of the dissolved tissue fluid gases. We have proceeded in the following way:—The subject of the experiment drinks at least a quart of warm water, and, after an interval of 10 to 15 minutes, enters the pressure chamber, the pressure being then raised a definite amount. Directly the desired pressure has been attained, he empties his bladder. Ten minutes later the bladder is emptied again. Samples of the urine passed are then run

into glass bulbs with rubber connections, care being taken to drive out any air bubbles that may be present. The rubber junctions are then clamped, and the dissolved gas subsequently pumped out by means of Hill's blood-pump, the volume determined, and the mixture analysed by the potash and pyrogallic acid method.

In this manner, a sample of urine, passed since the pressure limit had been reached, was available for analysis, and a series of specimens could be obtained. It was first, of course, necessary to determine the amount of gas dissolved by the urine under normal pressure conditions. Six analyses were made, and the mean volume of dissolved nitrogen per 100 c.c., reduced to 760 mm. and 0° C., was found to be 1·14 c.c. The individual observations, made at different times and under different circumstances, exhibit only a small range of variation, they are 1·21, 1·19, 0·97, 1·10, 1·31, 1·07, 1·14. The coefficient of variability determined by one of us (M. G.) is only $9{\cdot}5699 \pm 1{\cdot}8799$.

We are thus entitled to assume that, in our own cases, the coefficient of solubility for atmospheric nitrogen under normal barometric pressure, and at body temperature, is between 0·11 and 0·12.

We next determined the changes in the amount of dissolved nitrogen with varying pressures. The following are the results of a typical experiment:—

Experiment 31, 31.5.06.

M. G.—compressed to +30 lbs. in 10 minutes (2.50 p.m.).

The bladder was then emptied, and at 2.55 the bladder was emptied again, 135 c.c. of urine being passed, and Sample 1 was taken.

2.56—decompression commenced.

3.20 (+15 lbs.)—the bladder was emptied again (320 c.c.).

3.45—decompression completed, bladder emptied again (310 c.c.).

4.1—another sample taken (135 c.c. passed).

At 4.55 and 6.10 other samples were taken.

Analyses.

Sample.	Time and pressure.	Percentage of nitrogen.	Calculated N per cent., supposing urine followed the pressure.
1	Passed after 5 minutes under 30 lbs.	2·522	$1{\cdot}1 \times 3 = 3{\cdot}3$
2 and 3	Were spoiled		
4	At normal pressure, 16 minutes after decompression	2·373	1·1
5	70 minutes after decompression	1·107	1·1
6	245 minutes later	1·023	1·1

In another experiment the following were the results :—

Sample.	Time and pressure.	Percentage of nitrogen.	Calculated N per cent., supposing urine followed the pressure.
1	45 lbs., immediately	2·64	$1·1 \times 4 = 4·4$
2	" 8 minutes later	4·57	$1·1 \times 4 = 4·4$
3	" 9 "	4·69	$1·1 \times 4 = 4·4$
4	" 13 "	4·35	$1·1 \times 4 = 4·4$
5	" 23 "	4·57	$1·1 \times 4 = 4·4$
6	At 30 lbs. during decompression	4·252	$1·1 \times 3 = 3·3$

These results, amply confirmed by our other experiments (*vide* tables, pp. 26 and 27), merit some consideration.

First of all, we note that an exposure of more than five minutes to a positive pressure of 30 lbs. is necessary in order to produce saturation; the mean of five samples taken under these conditions is 1·99, as compared with 3·3, the theoretical value.

Saturation appears to be attained in 10 minutes,* however. Thus, the mean of seven samples, taken not less than 10 minutes after attaining the above-mentioned pressure, was 3·32. For a pressure of +45 lbs. the same statement appears to hold, but the time limit is probably slightly lower, as, on two occasions, full saturation was obtained in eight minutes. The mean of eight observations at this pressure, for exposures of less than 10 minutes, is 4·23, the theoretical value being 4·4.

The next point to notice is that the escape of dissolved gas is a much slower matter than could be expected. Thus, in experiments at +3 atmospheres, samples were taken when the pressure had fallen during slow decompression to +2 and +1 atmospheres. The means of 7 and 8 observations at these pressures were, respectively, 3·63 and 2·75, *i.e.*, the samples were super-saturated.

These results, however, are not surprising, since some of the urine taken in the specimen must have been separated from the blood while under the higher pressure, hence we could not assert, on the strength of these observations alone, that any definite retardation occurs in the equilibrating process. But, if we consider the analyses made after returning to the normal pressure, we find very strong evidence in support of such a view. In the experiment recorded above, a sample passed *sixteen* minutes after decompression contained 2·373 per cent. of nitrogen, in another experiment the amount was 1·66, the mean of 5 being 1·64.

* Saturation of the kidney under the conditions of diuresis is probably far quicker than that of other and less vascular organs.

Of samples passed immediately after decompression not one yielded less than 1·64 per cent., the mean of 6 being 1·99.

We are thus led to conclude that, even with a decompression rate of 20 minutes per atmosphere, the excess of dissolved nitrogen has not escaped entirely from the tissue fluids, even 15 minutes after decompression. As the matter is of importance, we must examine the validity of our method a little more closely. The accuracy of the analytical process itself was tested by submitting a sample of boiled water to a vacuum in the Hill pump and proceeding exactly as in the urine analyses. No measurable gas was obtained, so that the error due to leakage may be regarded as negligeable. In any case, we disregard analyses in which, owing to the presence of unusually large quantities of oxygen, we can reasonably suspect contamination with air. In general, only very small quantities of oxygen were found.

The admixture of urine that had collected in the bladder while the subject was exposed to a higher pressure would lead to erroneous results, but the *complete* emptying of the bladder at each observation avoids this source of fallacy. All the urine of the samples passed 15 minutes after decompression must have been separated from the blood after the pressure had fallen to + 0 lb., with the exception of the amount present in the tubules and renal pelves, this latter quantity being so small in comparison with the total volume (135 c.c.) passed, that the resultant error can hardly be appreciable.

That our experiments are not sufficiently numerous to admit of definite statement as to the exact time relations of the process may be granted; but the qualitative accuracy of the conclusion seems unassailable.

We have obtained a striking confirmation of our view in the following manner. At the caisson works now being carried out by the London County Council in connection with the new Rotherhithe Tunnel, a positive pressure of 14—17 lbs. is employed and only three minutes allowed for decompression.* We have analysed samples obtained from six caisson workers obtained directly after leaving the air lock, with the following result:—

	Nitrogen.
1†	1·595
2	1·658
3	1·506
4	1·414
5	1·747
6	1·744

* With such low pressures there is little risk in so short a decompression period.

† The men had some beer to drink and most of them passed water just before decompression.

It must be admitted that these observations indicate in a manner not to be disregarded the extreme danger of rapid decompression from high pressures. It might even be doubted whether 20 minutes per atmosphere is an absolutely safe allowance; indeed, a few fatal cases, recorded in the literature of caisson works, in which this time appears to have been allowed, support such a contention. It may well be, however, that a certain steepness of pressure-slope between dissolved and free gas is necessary for the formation of bubbles sufficiently large to produce injury.

So far as our observations go, with a decompression rate of 20 minutes an atmosphere the dissolved nitrogen falls in a given time to the same level, whatever be the height of pressure attained during the experiment. That is to say, the excess of dissolved nitrogen on returning to zero is no greater after exposure to three atmospheres than after raising the pressure to two atmospheres only. It would seem that the velocity of escape diminishes from some critical point. If this be so, it would be an argument for retarding the later stages of decompression in order that an equilibrium may be re-established on returning to normal conditions.

The causes underlying these results remain for subsequent consideration; in the light of other experiments we have carried out, we think it possible that a physical explanation will be found adequate to account for the facts, but our investigations are not yet sufficiently complete to permit its immediate statement.

A complete table of our analytical results is subjoined; the figures queried are possibly vitiated by experimental errors, we have no reason to doubt the accuracy of the others.

Our general conclusions from the present investigation are:—

(1) The body fluids of man exposed to compressed air absorb nitrogen in accordance with Dalton's law.

(2) Saturation of the body fluids is attained after exposure to pressures of +30—45 lbs. for from 10 to 15 minutes.*

(3) Even with a decompression rate of 20 minutes an atmosphere, equilibrium between dissolved and atmospheric nitrogen is not completed 15 minutes after decompression.

* Our results agree in principle with those deduced by V. Schrötter from theoretical considerations, *vide* 'Sauerstoff in der Prophylaxie und Therapie der Luftdruckerkrankungen,' Berlin, 1904, pp. 35—39.

Table I.—Urine Analyses from Hill and Greenwood's Experiments. Individual Observations.

Pressure.	N_2 per cent. found.	Means.	N_2 per cent. calculated, supposing urine followed the pressure.
+0 lb.	1·21, 1·19, 0·97, 1·10, 1·31, 1·07...............	1·14	1·1
+30 lbs. for less than 10 mins.	2·52, 1·67, 1·83, 2·41, 1·5	1·99	3·3
+30 lbs. for more than 10 mins.	3·32, 3·49, 3·29, 3·22, 3·42, 3·94, 2·57	3·32	3·3
+45 lbs. for less than 10 mins.	2·64, 4·57 (8 mins.), 5·68 (?) (8 mins.), 4·28	4·29	4·4
+45 lbs. for more than 10 mins.	4·54, 3·78, 4·52 (?), 4·69, 4·35, 4·57, 3·46, 3·94	4·23	4·4
+30 lbs. during decompression	4·01, 3·47, 3·52, 4·25, 3·68, 3·13, 3·33	3·63	3·3
+15 lbs. during decompression	2·40, 2·78, 2·96, 3·16, 2·60, 3·04, 2·35, 2·73	2·75	2·2
+0 lb. on decompression	1·84 (4 mins.), 2·21, 1·70, 2·30, 1·64, 2·24	1·99	1·1
+0 lb. 15 mins. after decompression	1·34, 1·37, 2·37, 1·66, 1·45 (10 mins.)	1·64	1·1
+0 lb. more than 15 mins. after decompression	1·28, 1·07, 1·02	1·13	1·1

Table II.

A. Rotherhithe Tunnel Workers.

Source of sample.	N_2 per cent. found.	N_2 per cent. calculated, supposing urine followed the pressure.
In tunnel (+17 lbs.)	2·38, 1·83	2·35
After decompression (decompression time, $3\frac{1}{2}$ mins.)	1·60, 1·66, 1·51, 1·41, 1·75, 1·74, 1·31, 1·63	1·1

B.* From Admiralty Diver C.

Depth.	Time below and N_2 per cent. found.	N_2 per cent. calculated, supposing urine followed the pressure.
80 feet	Below 46 mins. 20 secs. Ascended in 6 mins. 5 secs.—Sample taken 20 mins. 30 secs. after ascent: $N_2 = 1{\cdot}73$	1·1
84 "	Below 46 mins. Ascended in 5 mins.—Sample taken 11 mins. after ascent: $N_2 = 1{\cdot}60$	1·1
72 "	Below 44 mins. Ascended in 6 mins.—Sample taken 5 mins. after ascent: $N_2 = 2{\cdot}11$	1·1
	" 20 " " $N_2 = 1{\cdot}03$	1·1
80 "	Below 46 mins. Ascended in $4\frac{1}{2}$ mins.—Sample taken 4 mins. after ascent: $N_2 = 2{\cdot}50$	1·1
	" $20\frac{1}{2}$ " " $N_2 = 1{\cdot}38$	1·1

* For these samples we are indebted to Dr. Haldane, Lieutenant Damant, and Mr. Cato.

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